



## **Wind Farms Design and Optimization**

### **Presentation of TOPFARM and EERA-DTOC**

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# Wind Farms Design and Optimization

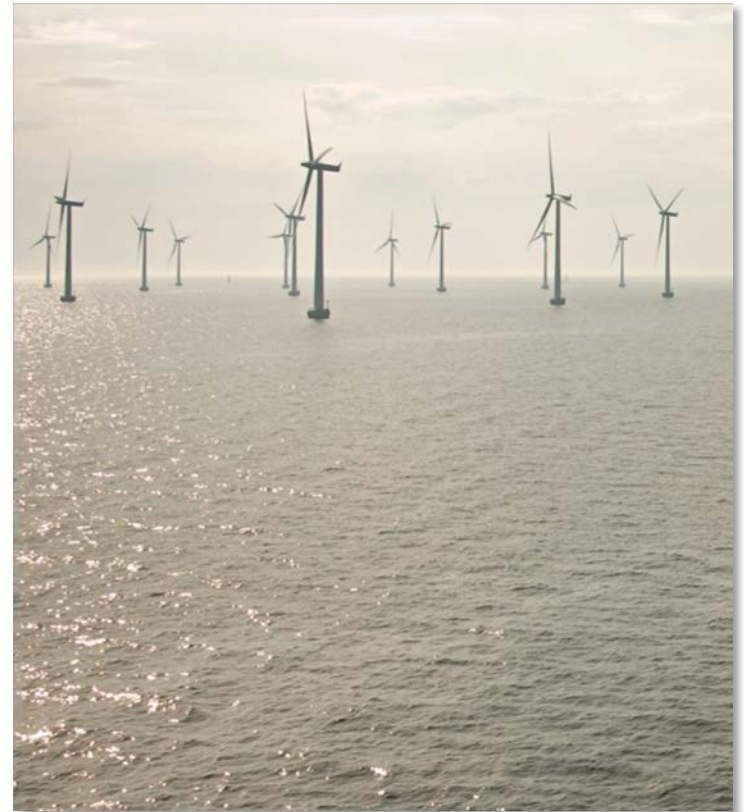
Presentation of **TOPFARM** and **EERA-DTOC**

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Aero-Elastic Design Section  
DTU – Wind Energy, Risø

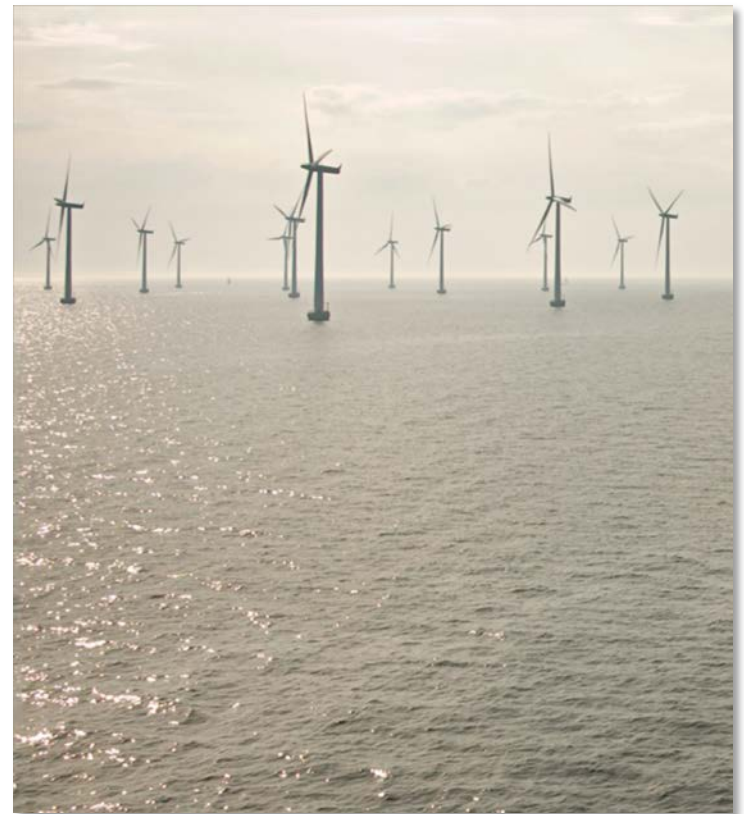
**DTU Wind Energy**  
Department of Wind Energy

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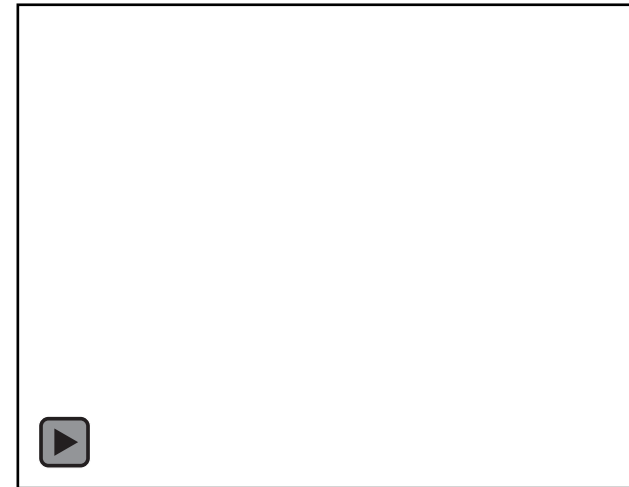
# Outline

- Background
- TOPFARM
  - Main Ideas
  - System Overview
  - Some Results
  - Feedbacks from the industry
- Unified Framework
- TOPFARM II
  - Main Ideas
  - System Overview
- EERA-DTOC
  - Main Idea
  - System Overview
- Conclusions



# Background

- Aero-Elastic Design Section is principally interested in wind turbine design
- Wind turbines design depends of inflow inputs (upstream wakes)
- Dynamic Wake Meandering can calculate wake induced loads
- Other wake models can calculate power production (e.g. FUGA)
- How can we introduce these tools together into wind farm design?



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# TOPFARM

## Main Idea

- **TOPFARM** = Topology **OP**timization of wind **FARM**
- **EU-FP6** Funded project 2006-2010
- **Multi-fidelity** framework for wind farm layout optimization
- Optimization from the **wind farm developer** perspective
- Objective function is the wind farm lifetime **financial balance**
- The cost models take into account:
  - Wake effects on power production
  - Wake effects on wind turbines components fatigue
  - Offshore foundation costs
  - Electrical grid cabling
  - Financial parameters

# TOPFARM System Overview

**Multi-fidelity:**  
2<sup>nd</sup> Level

**Optimization:**  
Gradient based

**Meta  
model**

**Dynamic Wake  
Meandering  
model**

**Aero-elastic  
model  
(HAWC2)**

**Layout  
Optimization**

**Stationary  
wake model**

**Foundations  
cost**

**Annual Energy  
Production**

**Fatigue  
induced costs**

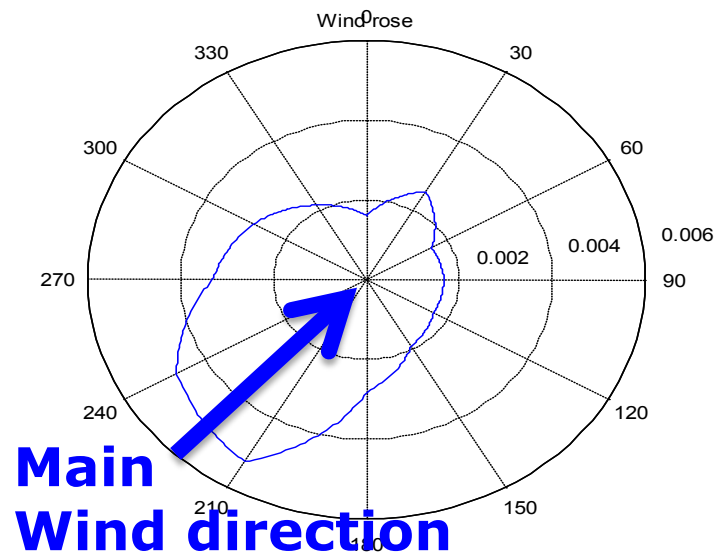
**Electrical  
grid cost**

**Financial  
Balance**

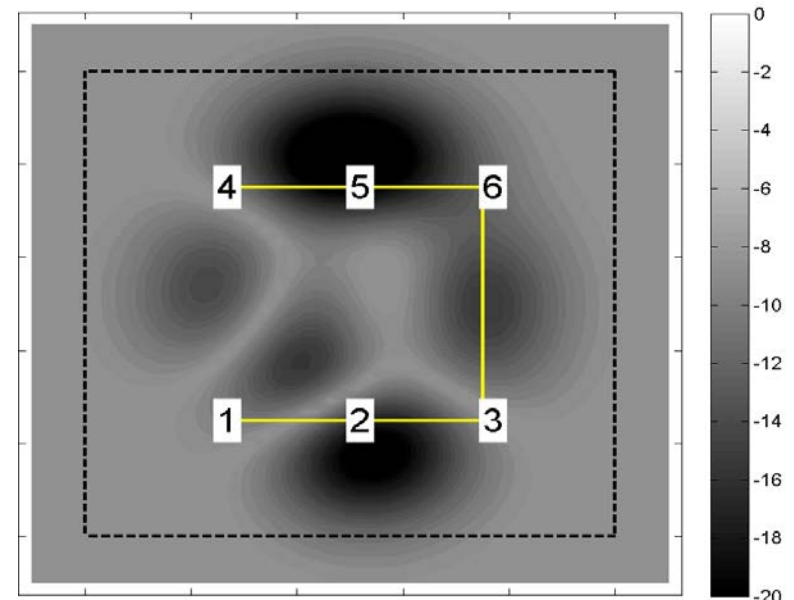
# TOPFARM

## Demonstration example 1

- Generic offshore wind farm:
  - 6 × 5MW offshore wind turbines
  - Water depths between 4m and 20m



Wind direction probability  
density distribution



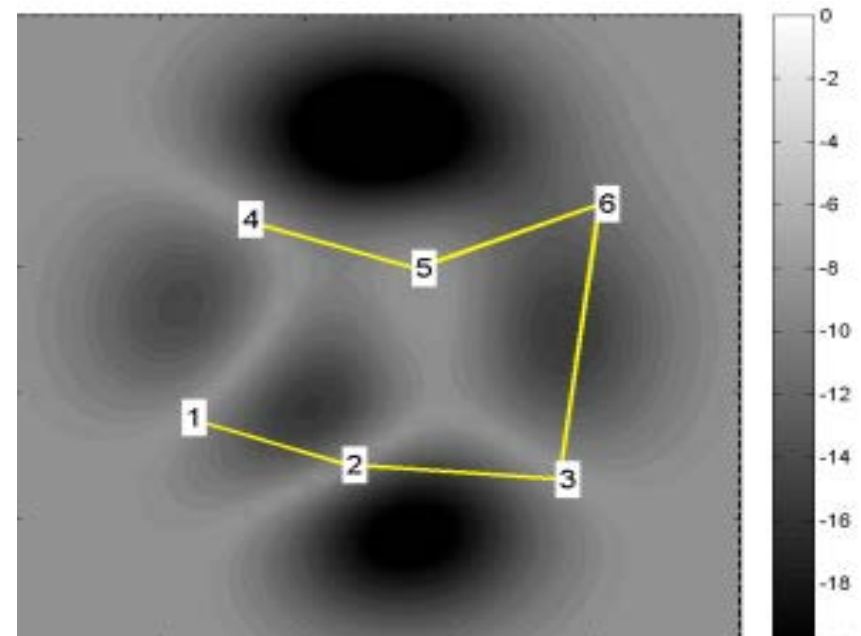
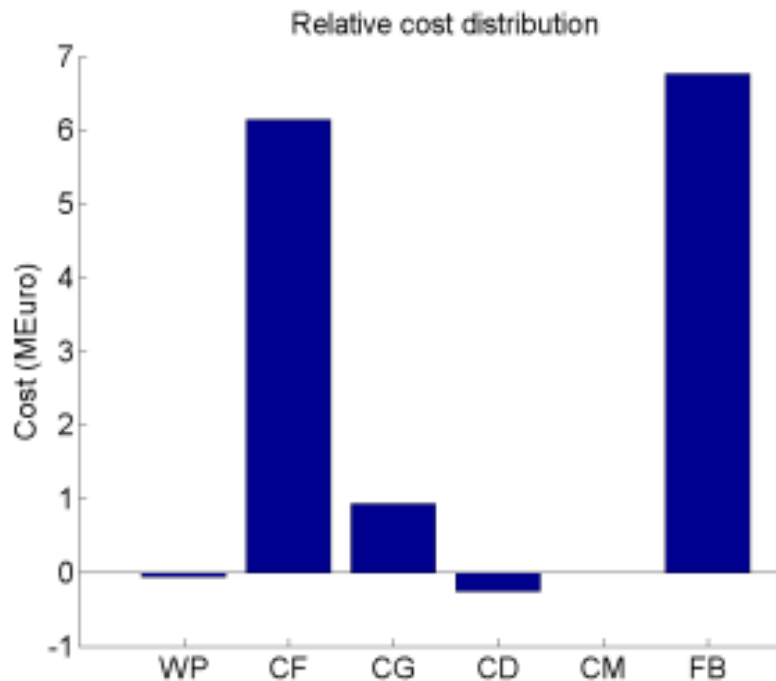
Gray color: Water depth [m]  
Yellow line: Electrical grid



# TOPFARM

## Demonstration example 1

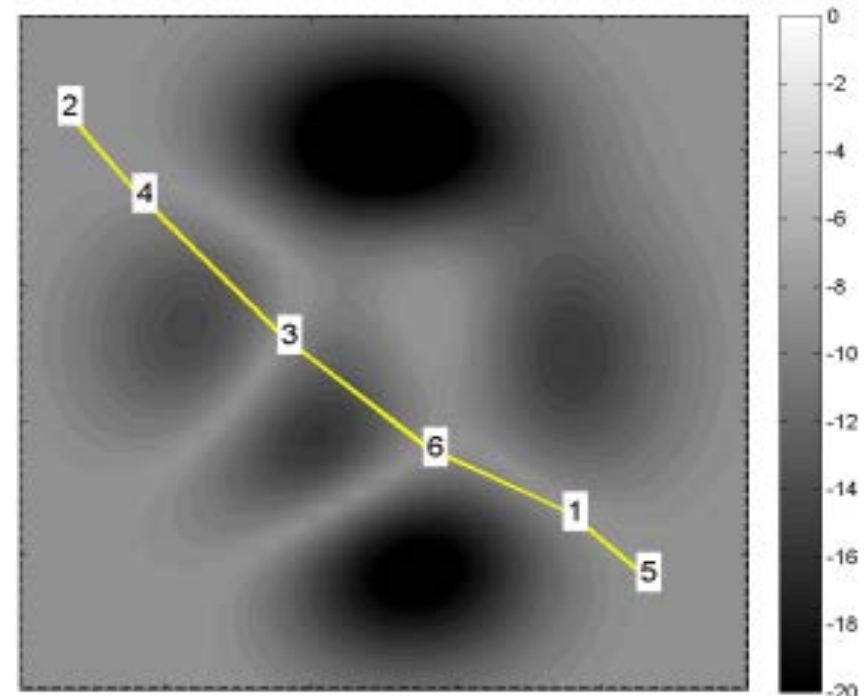
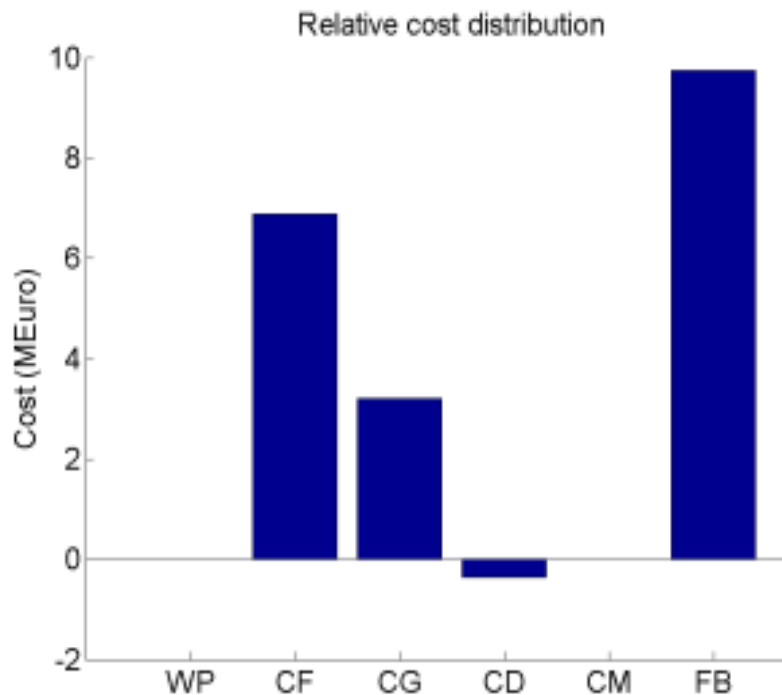
- Result of a gradient based optimization:



# TOPFARM

## Demonstration example 1

- Result of a genetic algorithm + gradient based optimization



# TOPFARM

## Demonstration example 2

- Middelgrunden

# TOPFARM

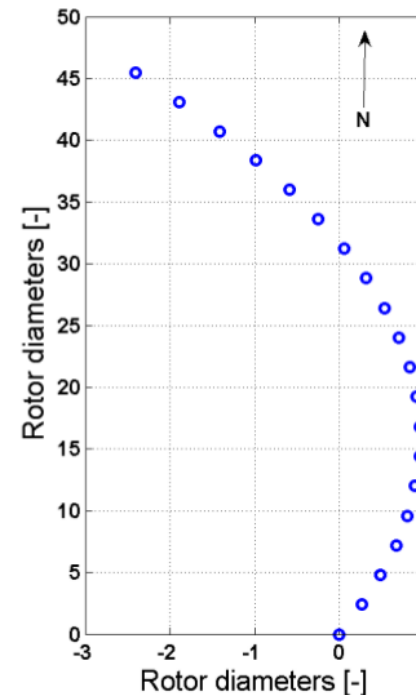
## Demonstration example 2

- Middelgrunden



Allowed wind turbine region

Mast

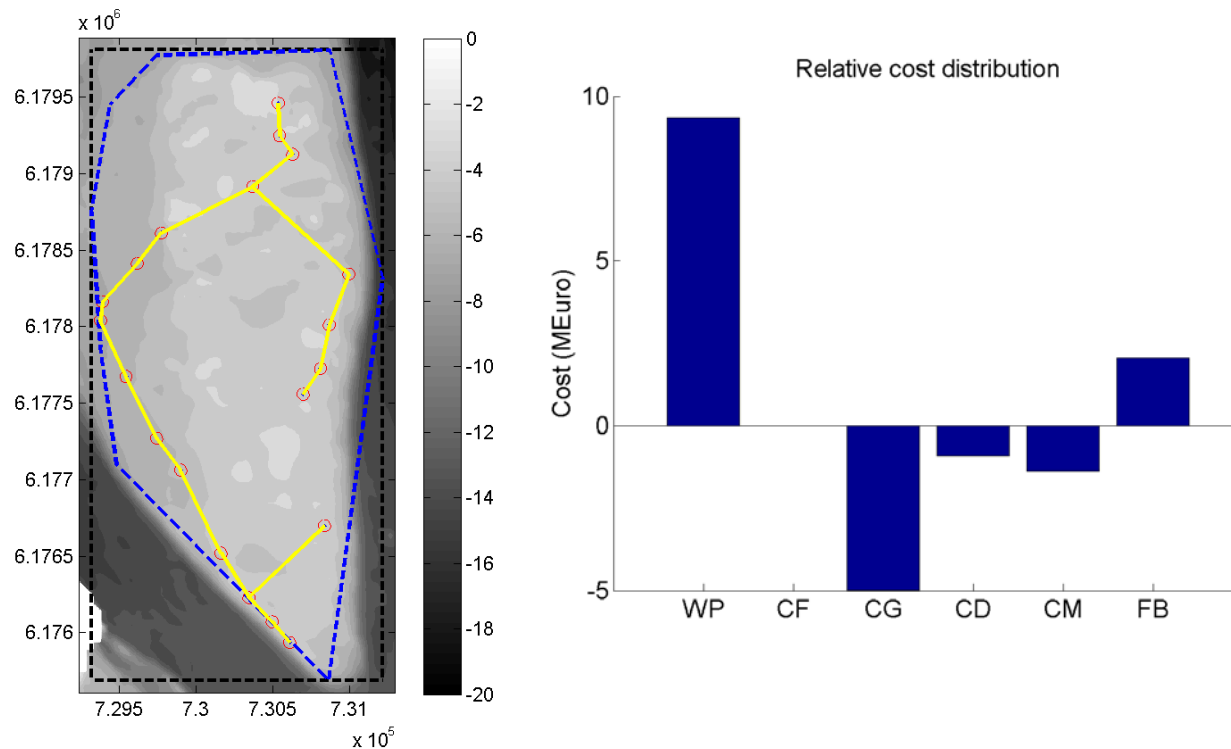


Middelgrunden layout

# TOPFARM

## Demonstration example 2

- Middelgrunden iterations: 1000 SGA + 20 SLP

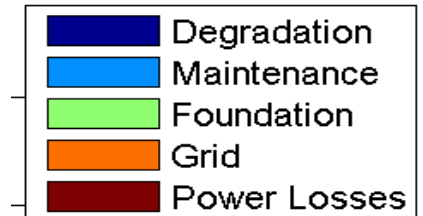
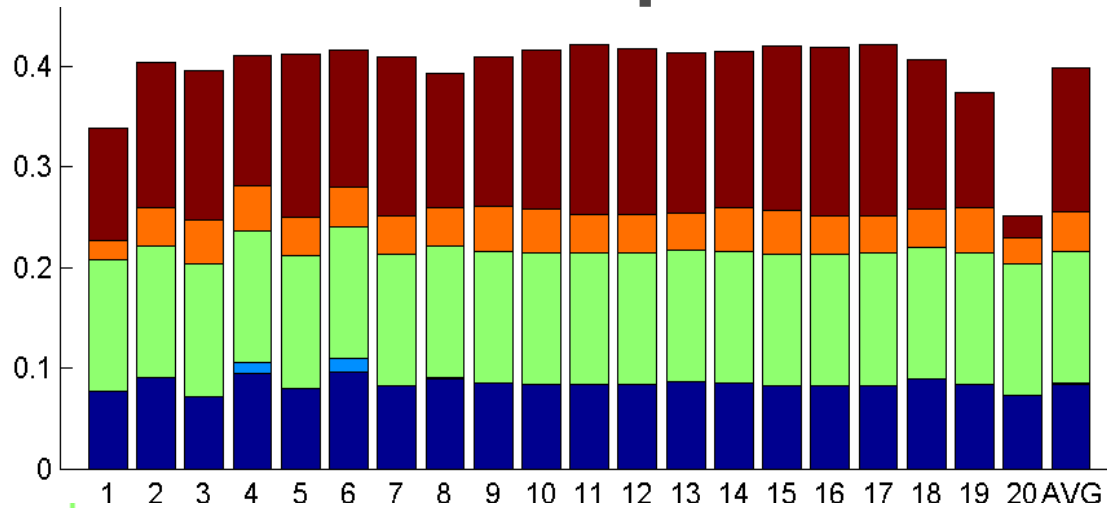


**Optimum wind farm layout (left) and financial balance cost distribution relative to baseline design (right).**

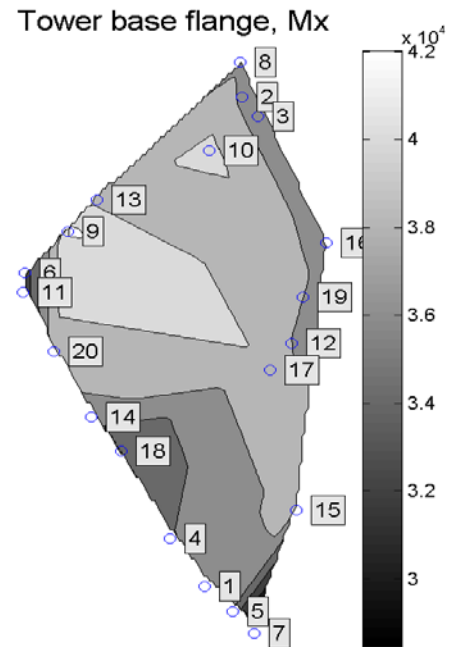
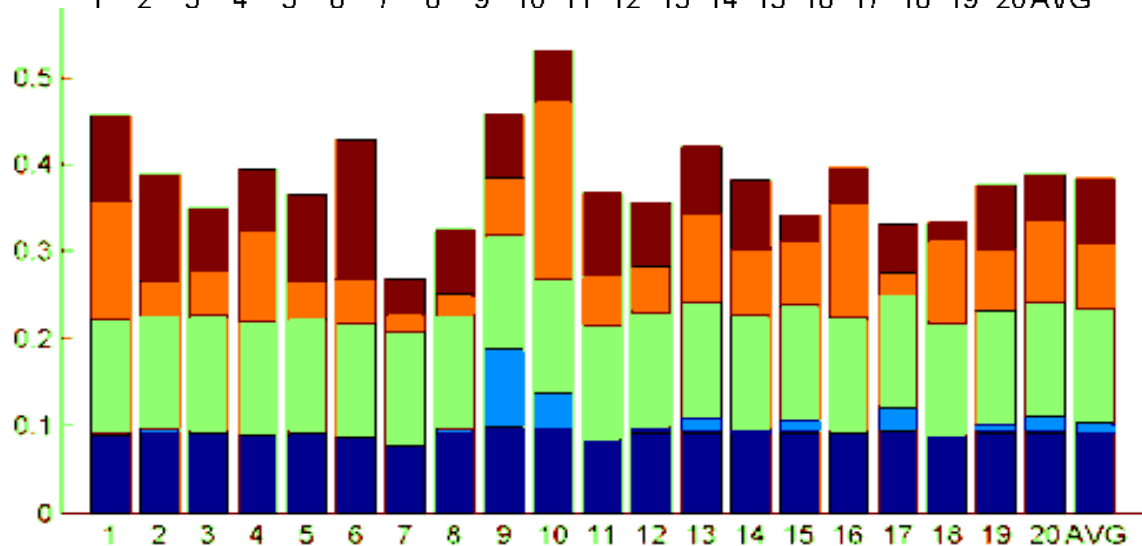
# TOPFARM

## Demonstration example 2

Before



After



# TOPFARM

## Feedbacks from the wind industry

- Nice to be able to estimate the wake induced fatigue
- Workflow not ready for a *push-of-a-button* holistic solution
- Multi-disciplinary design tools are difficult to be use in large “bureaucratic” organizations.
- Expert(s) opinion(s) within optimization loop, *somehow*
- Wish for an open framework, to use their own cost & physical models they already have experience with.

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# Unified Framework

- In Python
- Based on OpenMDAO (supported by NASA)
- Based on a common wind energy library between DTU & NREL to connect models
- Open source Framework & open/closed modules
- Possibility to easily define and connect your own cost and physical models

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# TOPFARM II

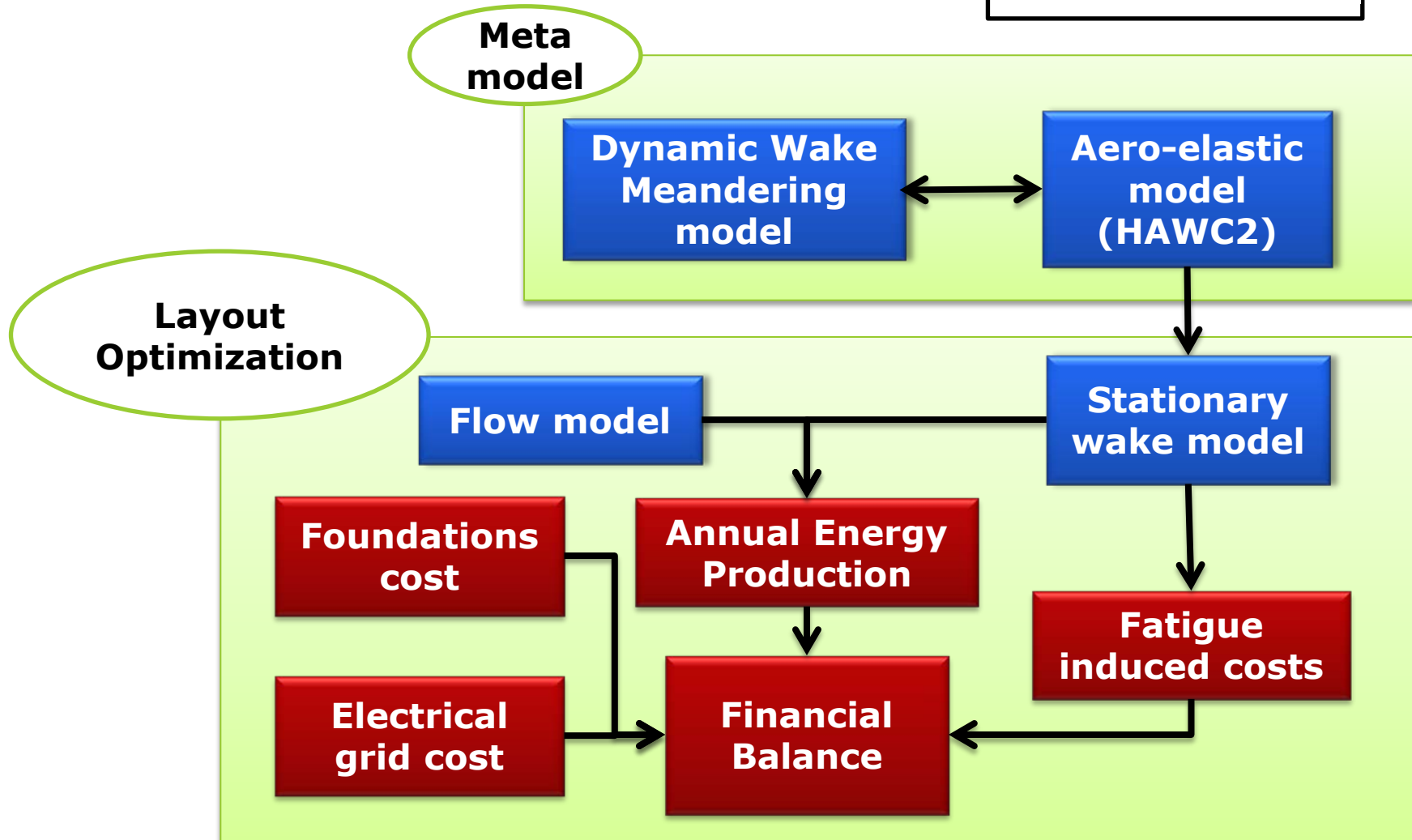
## Main Ideas

- Use FUGA as the main stationary wake model
- Use WAsP & WRF engine to calculate accurate local wind resources
- 3<sup>rd</sup> level of fidelity: running the whole wind farm with DWM
- More advanced multi-fidelity optimization strategy
- Higher degree of parallelization
- Expert driven iterative design process
- GUI connected to WAsP

# TOPFARM II

## System Overview

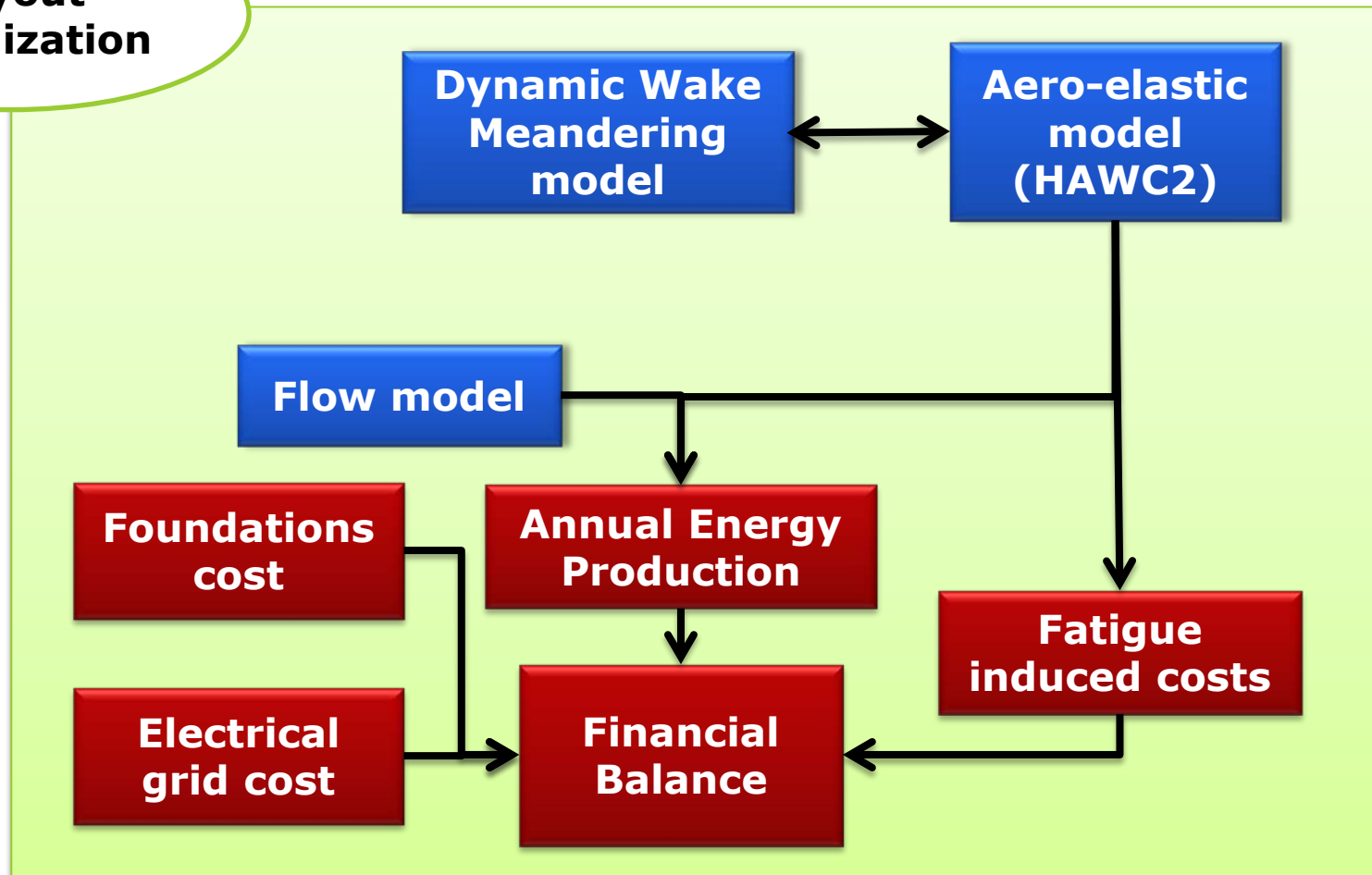
**Multi-fidelity:**  
2<sup>nd</sup> Level



# TOPFARM II System Overview

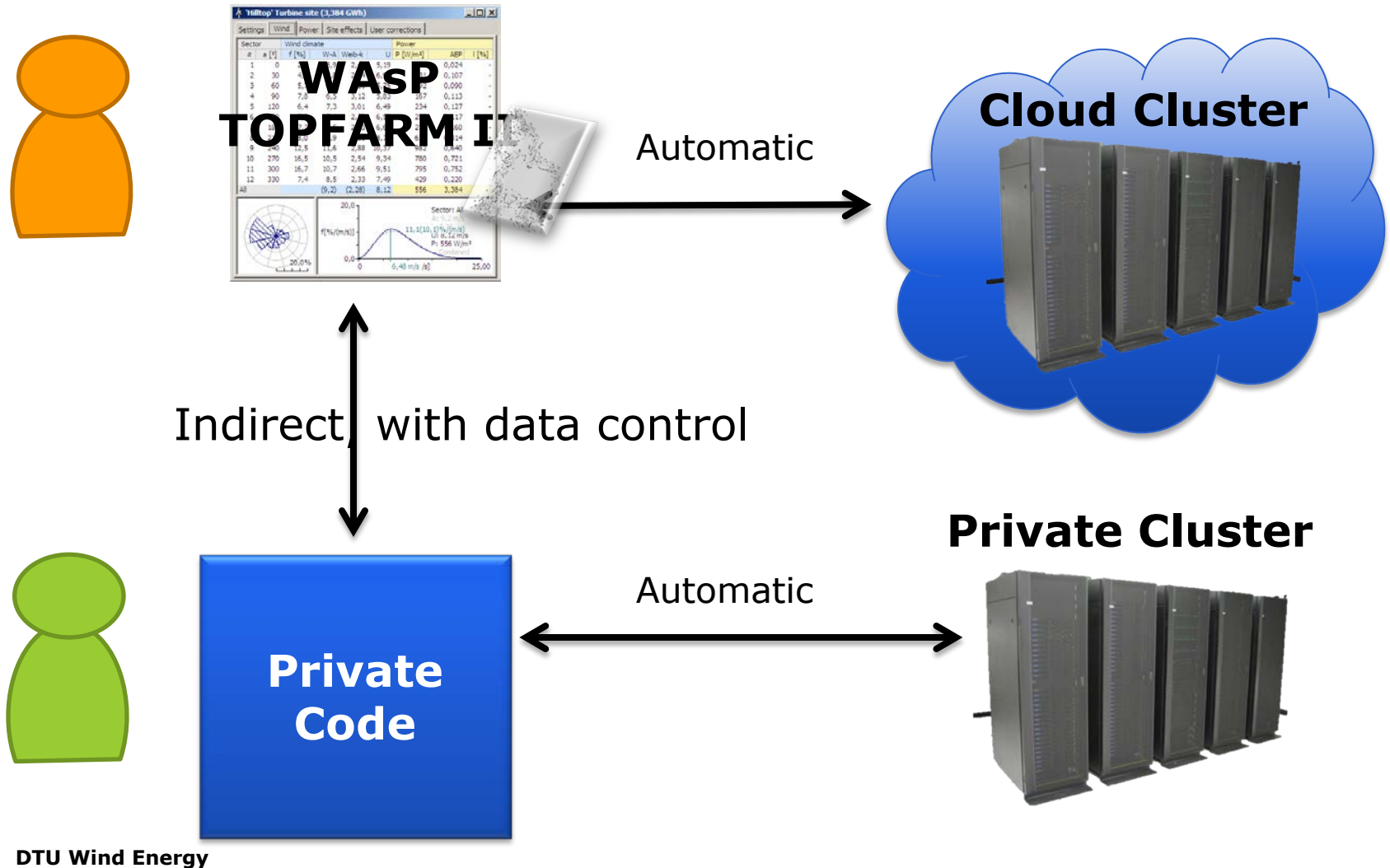
**Multi-fidelity:**  
3<sup>rd</sup> Level

Layout  
Optimization



# TOPFARM II

## User Scenario



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# EERA-DTOC

## Main Ideas

- **EERA: European Energy Research Alliance**
- **DTOC: Design Tool for Offshore (wind farm) Clusters**
- EU-FP7 funded project, 2012-2015
- Focus on designing wind farm **clusters** considering:
  - Inter wind farms **wake losses**
  - Inter wind farms **electrical cabling**
- Work is underway to deliver an integrated tool for the design of individual wind farms and clusters of wind farms
- The tool is composed of existing models as available throughout Europe
- The tool will be available in December 2014



# EERA-DTOC summary slide



## EERA-DTOC

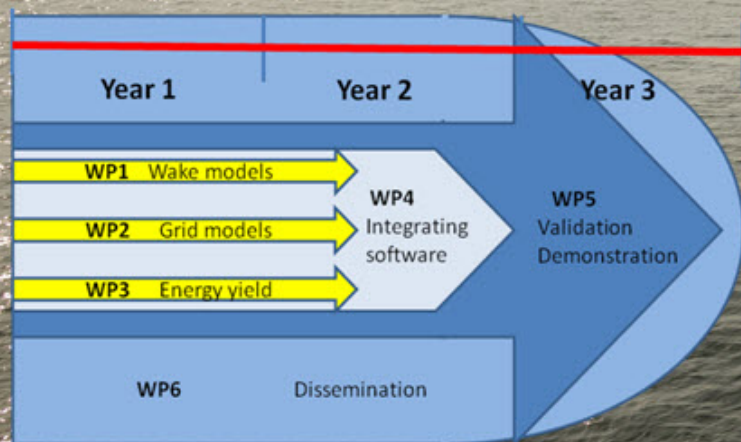
European Energy Research Alliance - Design Tools for Offshore Clusters

Charlotte Hasager, Gregor Giebel, Pierre-Elouan Rethore, EERA Wind members and industry

Contact: cbha@dtu.dk or grgi@dtu.dk, mob +45 4056 5095



Start 1 January 2012, runs for 3.5 years  
Total funding is ~4 M€, EU share is 2.9 M€.



## Product Vision:

A robust, efficient, easy to use and flexible **tool** created to facilitate the **optimised design of** individual and clusters of offshore wind farms.

A keystone of this optimisation is the **precise prediction of the future long term wind farm energy yield and its associated uncertainty.**

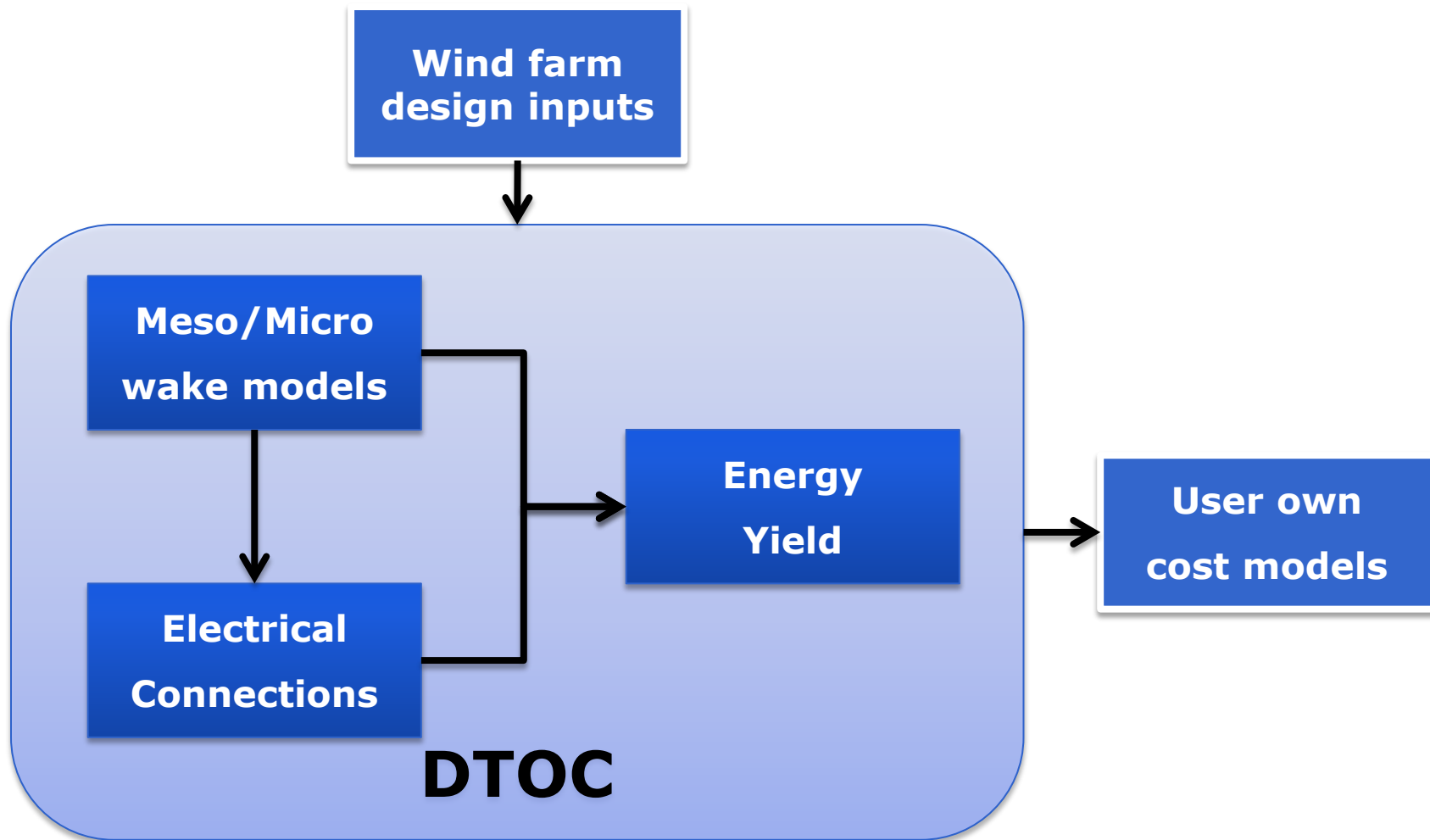


[www.EERA-DTOC.eu](http://www.EERA-DTOC.eu)

Risø Campus  
Frederiksborgvej 399, P.O. Box 49, Build. 118  
DK-4000 Roskilde, Denmark  
[www.vindenergi.dtu.dk](http://www.vindenergi.dtu.dk)

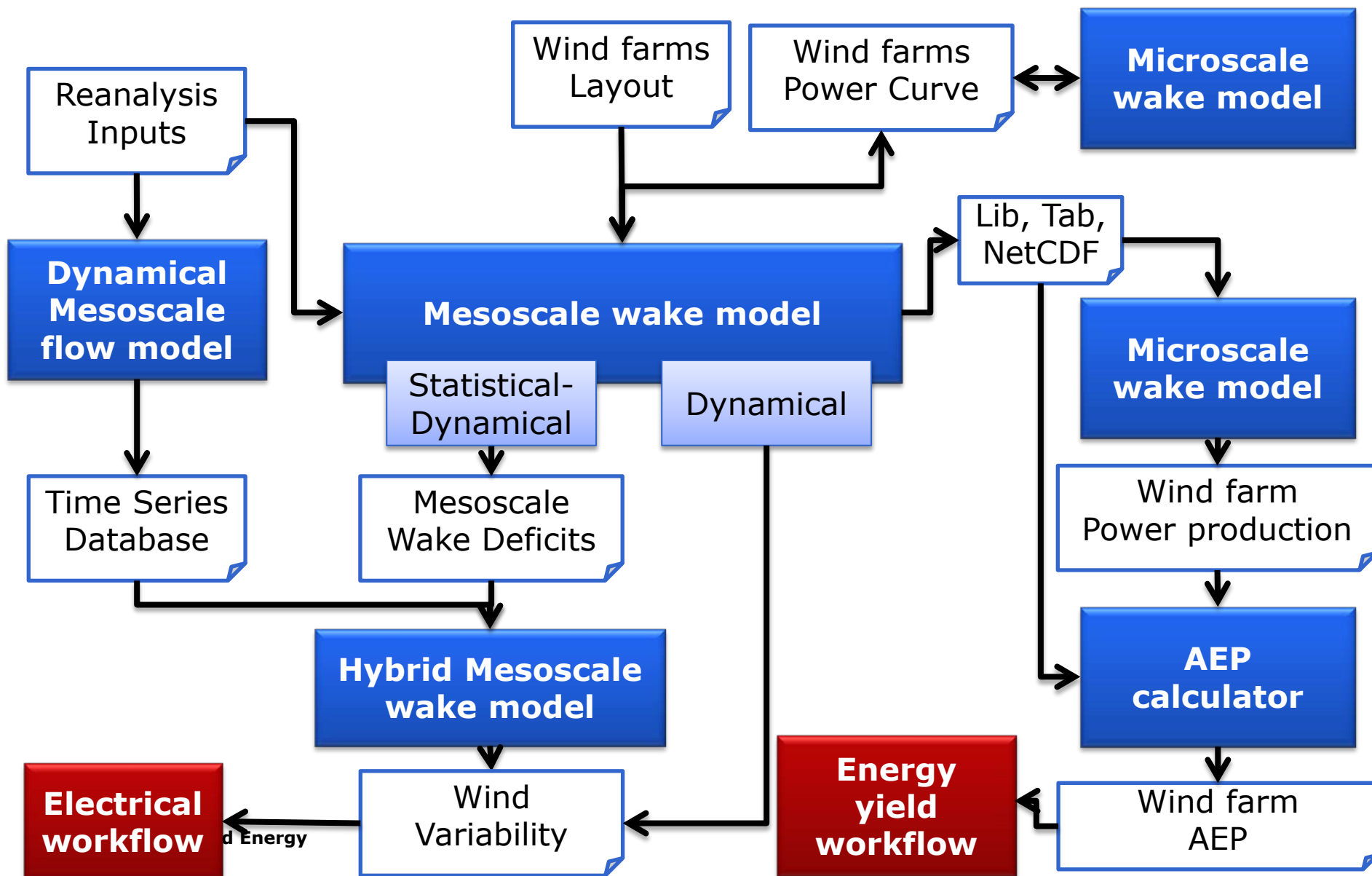
# EERA-DTOC

## System Global Overview



# EERA-DTOC

## Wake Models Workflow



# EERA-DTOC

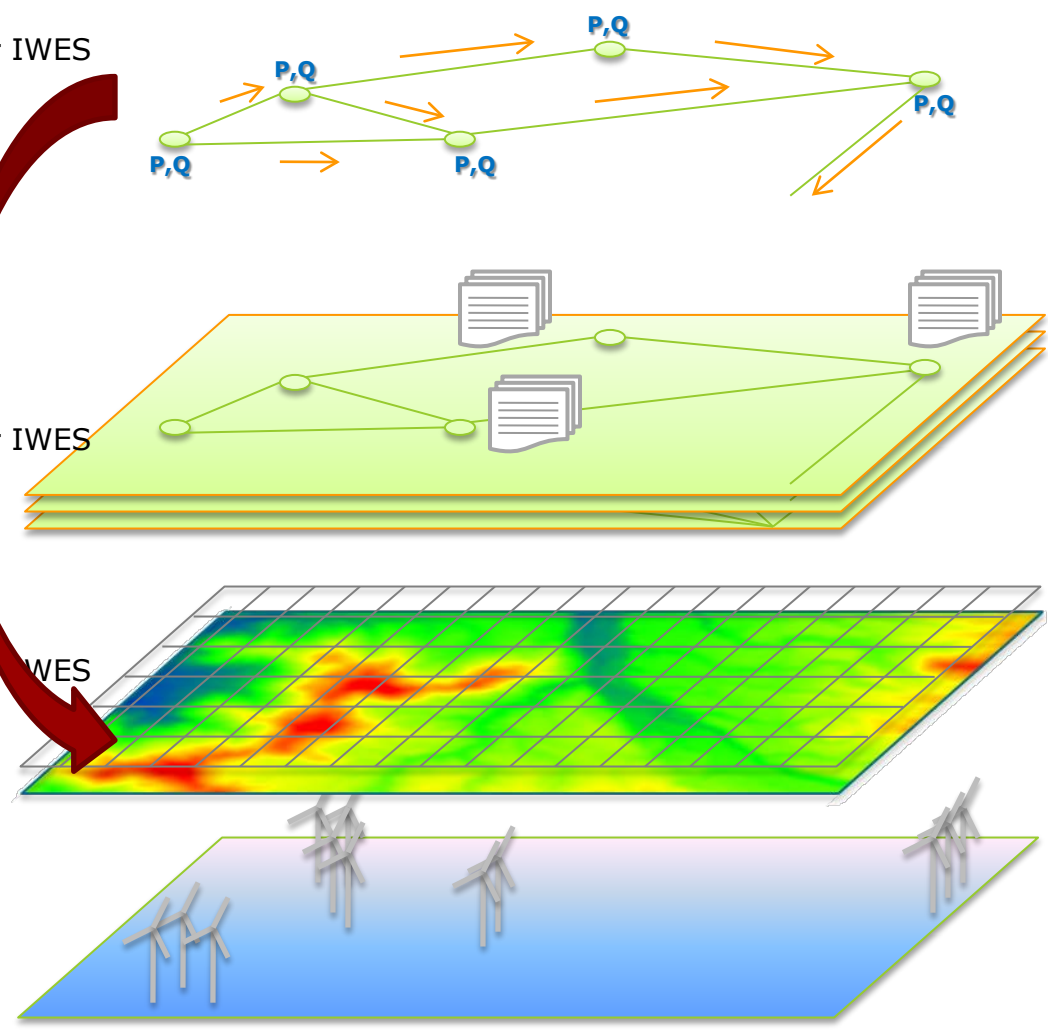
## Electrical Grid Models Workflow

• Fraunhofer IWES

• Strath  
• SINTEF

• SINTEF  
• Fraunhofer IWES  
• Strath  
• Statoil  
• Hexicon

• Risoe DTU  
• Fraunhofer IWES  
• CIEMAT



**WCMS model**  
Analysis of the availability  
of power plant system  
services

**Grid Codes compliance**  
PSS/e & PSCAD/EMTDC  
**Transient analysis**

**NET-OP model**  
Grid optimization  
**Steady-state**

**Analysis** on variability &  
predictability

**CorWind model**

Off-shore development  
**Wake modelling**

2.  
4

2.  
3

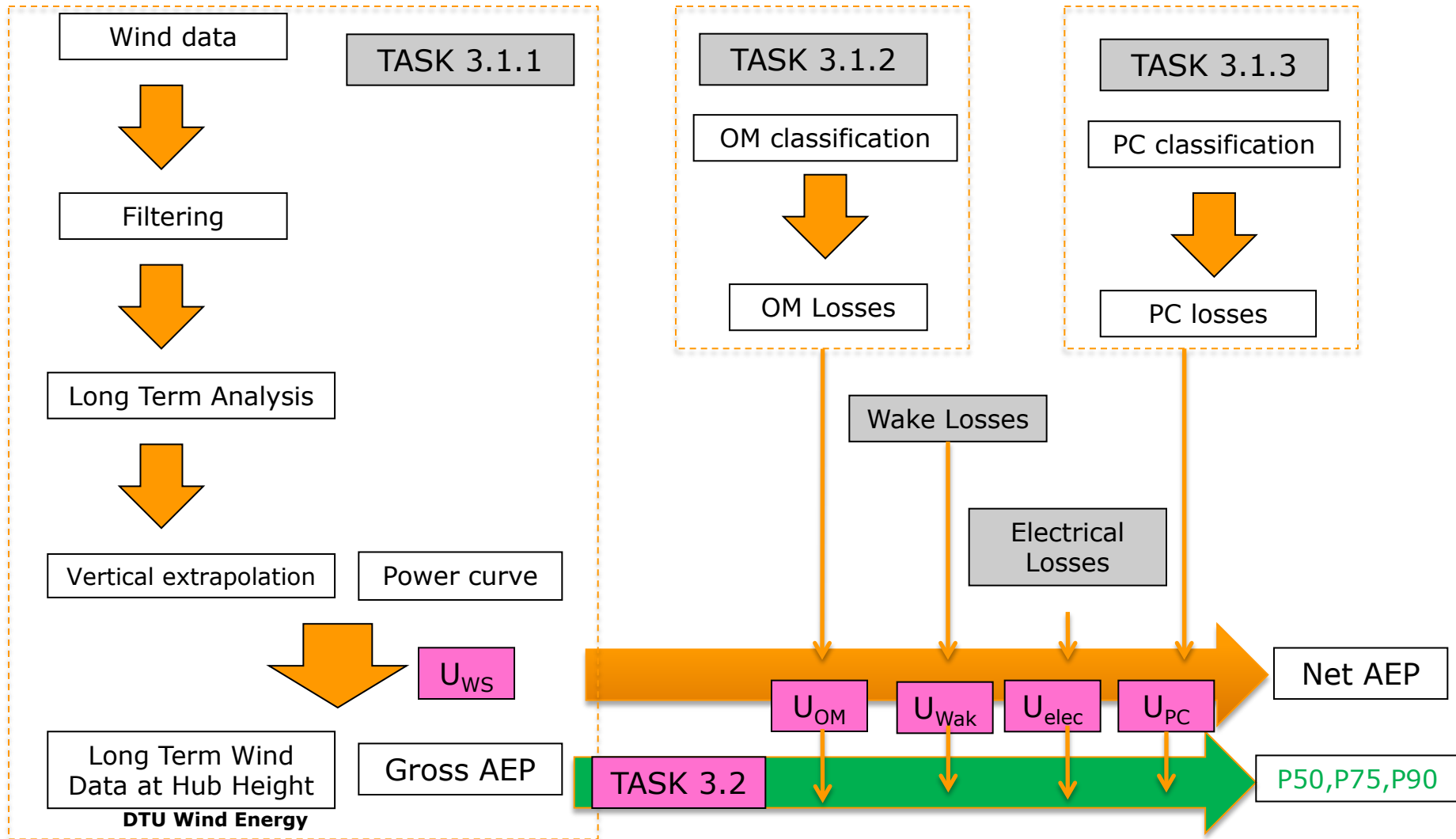
2.  
2

2.  
1

WP  
1

# EERA-DTOC

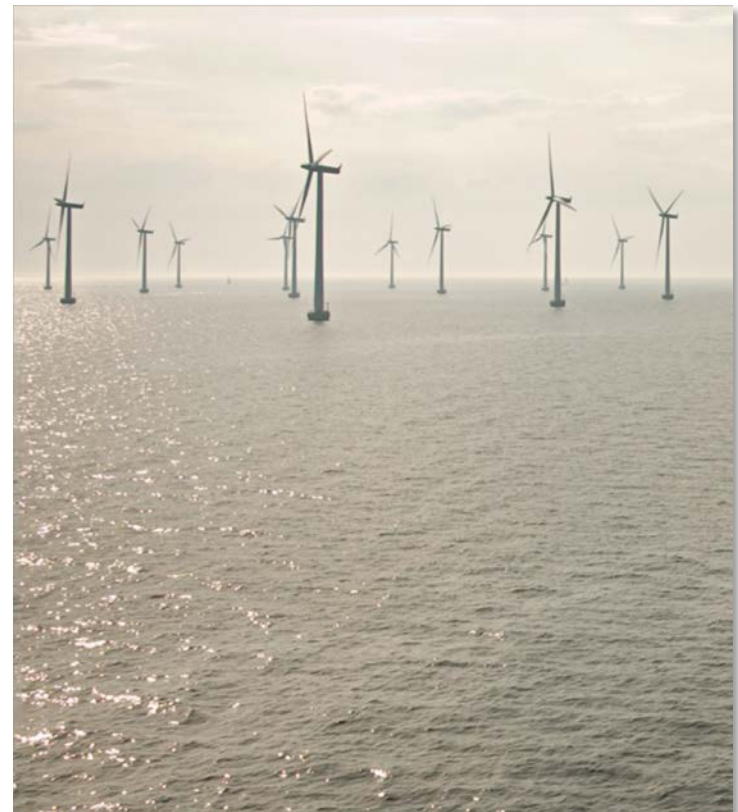
## Energy Yield Models Workflow





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## Conclusions

- “press-of-a-button” is not expert friendly
- Open framework is important
- Multi-disciplinary = Multi-user = Communication “challenges”
- Wake induced fatigue is relevant for wind farm design & optimization
- In the future we will have to take the potential wind farms into account in the risk analysis



**Invitation to workshop on  
Offshore Wind Farm Clusters: Focus on Northern European Seas  
London, UK, 6 June 2013 from 9.00 to 17.00**

In line with the targets of the European Strategic Energy Technology Plan (SET Plan) of the European Commission, the offshore wind energy industry in Europe is to benefit by research and development by two large international projects co-funded by the European Union.

The projects are **Cluster Design** and **EERA DTOC**.

The workshop is aimed at developers of offshore wind farm clusters, strategic planner and transmission system operators.

The workshop will include a series of presentations from the participants of Cluster Design and EERA DTOC. Keynote speakers: Peter Hauge Madsen (DTU Wind Energy), Rory Donnelly (3E), Mariano Faiella (IWES Fraunhofer), Elena Cantero (CENER), Gerard Schepers (ECN), Gregor Giebel (DTU Wind Energy), Pierre-Elouan Réthoré (DTU Wind Energy),

EERA DTOC is European Energy Research Alliance – Design Tools for Offshore Wind Farm Clusters

Venue: Renewable Energy System (RES) in London

For further information, please visit our web-sites

FP7-ENERGY-2011-1/n° 282797 EERA DTOC <http://www.eera-dtoc.eu>

FP7-ENERGY-2011-1/n° 283145 Cluster Design <http://www.cluster-design.eu/>

**DTU Wind Energy**